Lunar Dust and Lunar Simulant Activation, Monitoring, Solution and Cellular Toxicity Properties

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During the Apollo missions, many undesirable situations were encountered that must be mitigated prior to returning humans to the moon. Lunar dust (that part of the lunar regolith less than 20 μm in diameter) was found to produce several problems with astronaut's suits and helmets, mechanical seals and equipment, and could have conceivably produced harmful physiological effects for the astronauts. For instance, the abrasive nature of the dust was found to cause malfunctions of various joints and seals of the spacecraft and suits. Additionally, though efforts were made to exclude lunar dust from the cabin of the lunar module, a significant amount of material nonetheless found its way inside. With the loss of gravity correlated with ascent of the lunar module from the lunar surface to rendezvous with the command module, much of the major portions of the contaminating soil and dust began to float, irritating the astronaut's eyes and being inhaled into their lungs. Our goal has been to understand some of the properties of lunar dust that could lead to possible hazards for humans.

Due to the lack of an atmosphere, there is nothing to protect the lunar soil from ultraviolet radiation, solar wind, and meteorite impacts. These processes could all serve to "activate" the soil, or produce reactive surface species. In order to understand the possible toxic effects of the reactive dust, it is necessary to "reactivate" the dust, as samples returned during the Apollo missions were exposed to the atmosphere of the Earth. We have used grinding and UV exposure to mimic some of the processes occurring on the Moon. The level of activation has been monitored using two methods: fluorescence spectroscopy and electron paramagnetic resonance spectroscopy (EPR). These techniques allow the monitoring of hydroxyl radical production in solution. We have found that grinding of lunar dust produces 2-3 times the concentration of hydroxyl radicals as lunar simulant and 10 times that of quartz. Exposure of the lunar dust to UV radiation under vacuum was also found to lead to hydroxyl radical production. After grinding, we have also monitored loss of reactivity of the dusts by exposing them to conditions of known humidity and temperature. From these tests, it was found that the reactivity half-life of lunar simulant is approximately 3 hours, while that of quartz is approximately 2 hours.

Placing lunar dust in solution could lead to effects on mechanical and physiological systems, as well as other biological systems. For instance, while it is known that lunar dust is highly abrasive and caused a variety of problems with suits and equipment during Apollo, it is unknown as to how these properties might be affected in the presence of water or other liquids. It is possible that the dust may release minerals (e.g., metallic nanophase Fe) into solution that could speed corrosion or rust. Also, as lunar dust produces hydroxyl radicals (and possibly other reactive oxygen species) in solution, these radicals could also lead to the breakdown of suit or habitat materials. In the body (i.e., in lung solution), the effects could be two-fold. First, if the lunar dust dissolves, it may release an excess of elements (such as zero-valence metallic Fe) that are necessary for bodily functions but only in certain concentration ranges. For lunar dust, the presence of nanophase iron being released into the body is a concern. Secondly, the hydroxyl radicals or other reactive oxygen species produced by the dust in solution could conceivably interact with cells, leading to various problems. We have studied the dissolution of both ground and unground lunar simulant in buffer solutions of different pH. The concentration of a number of species was determined using mass spectrometry. These studies showed that lowering the pH of the solution causes a dramatic increase in the amount of each element released into solution and that grinding also produces higher concentrations.

Finally, we have performed initial tests aimed at understanding the effects of lunar simulant on cellular systems. Alveolar epithelial cells were cultured and exposed to different concentrations of dust suspended in cell culture media. After predetermined amounts of time, the media was removed and the concentrations of important inflammatory cytokines (IL6, IL8, and TNF-α) were measured. The results of these tests are being used to develop the correct protocols for tests to be performed using lunar dust samples.